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Large area color effects in polymer replica of black silicon

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We present a method for fabrication of cost efficient, large area, and patterned structural color filters in polymer by replication of black silicon surface structures using a PDMS mold and UV-NIL. In transmission of directional white light, the imprinted polymer show different colors, depending on the type of black silicon structure on the master. Combined with patterning of the black silicon structures by UV-lithography, the results facilitate novel applications of black silicon replications for decorations of polymer components.

Black silicon is random tapered nanostructures that can be fabricated by mask less Reactive Ion Etching (RIE) over large areas [1]. Replication from black silicon has previously been used to fabricate anti-reflecting polymer surfaces. Sainiemi *et. al.* [2] fabricated anti-reflecting structures in Ormocer by a UV-NIL process, using an h-PDMS stamp casted from a black silicon wafer. Ting *et. al.* [3] reported a low cost fabrication method for large area anti-reflecting films, by electroplating Co-Ni shims from 4 inch black silicon substrates. The shims were used as mold for a hot-embossing process in PMMA.

In this study black silicon was fabricated using mask less RIE on bare silicon wafers. The surface structures were patterned using UV lithography and RIE, removing the unmasked black silicon structures (Fig. 4a). A PDMS replica (Sylgard 184) of the silicon surface was created by casting and used as stamp to imprint the structures in UV-curable hybrid material,Ormocomp (Microresist Technology), spun on a glass substrate. The imprinting was performed by applying a hydrostatic pressure (10 bar) on the backside of the stamp (Obducat NIL Imprinter 2.5) for 10 min at room temperature. The imprinted films were cured using a UV-light source.

The replication of black silicon in polymer is characterized by SEM (Fig. 3). While the black silicon wafers show the antireflection property of the nanostructures (Fig. 2a), the imprinted polymer substrate shows a variety of colors in transmission of directional white light (Fig. 2b). Different colors correspond to difference in the black silicon structures due to non-uniformity of the RIE process near the wafer edge. Transmission spectra for the imprinted polymer are shown in Fig. 1. UV lithography patterning of the silicon master is transferred to the imprinted polymer (Fig. 4).

[1] H. Jansen *et. al.*, J. Micromech. Microeng. 5 (1995) 115-120.

[2] L. Sainiemi *et. al.*, Adv. Mater. 23 (2011) 122-126.

[3] C.-J. Ting *et. al.*, Nanotechnology 19 (2008) 205301.

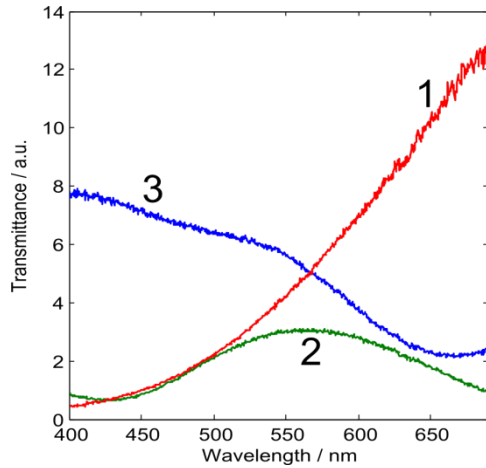


Figure 1: Transmission spectra of three different areas on imprinted ORMOCOMP (Fig. 2b). Depending on the structure type different wavelengths are scattered, leading to different transmission spectra.

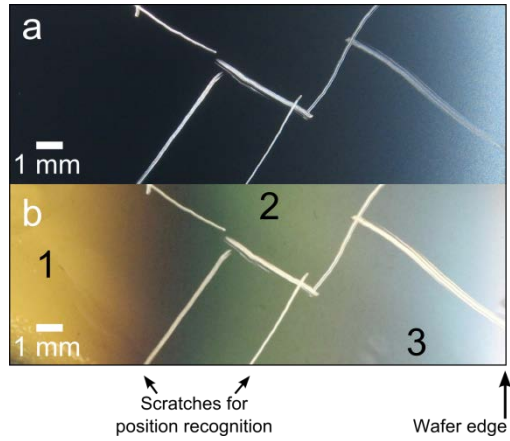


Figure 2: a) Section of black silicon master near the wafer edge. Non-uniform etch gives variations in structures. b) Replica in ORMOCOMP on glass substrate held against white light. Variations in black silicon lead to different scattering properties of imprinted structure.

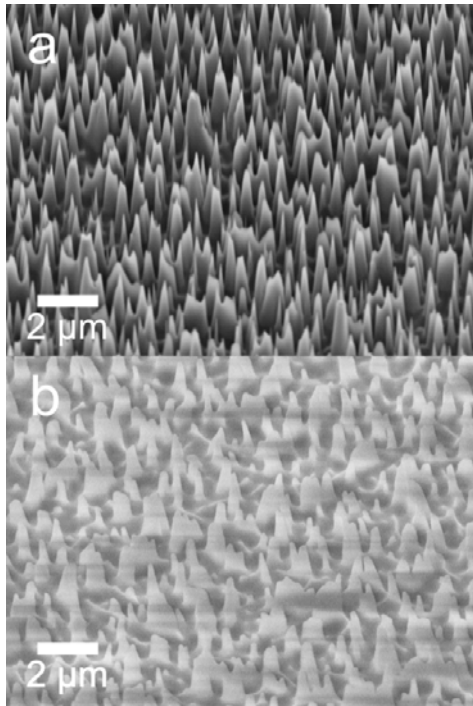


Figure 3: a) SEM picture of black silicon structure in area 3 (Fig. 2). b) SEM picture of corresponding replica in ORMOCOMP, made from a casted PDMS mold. The structures are rounded during the replication process.

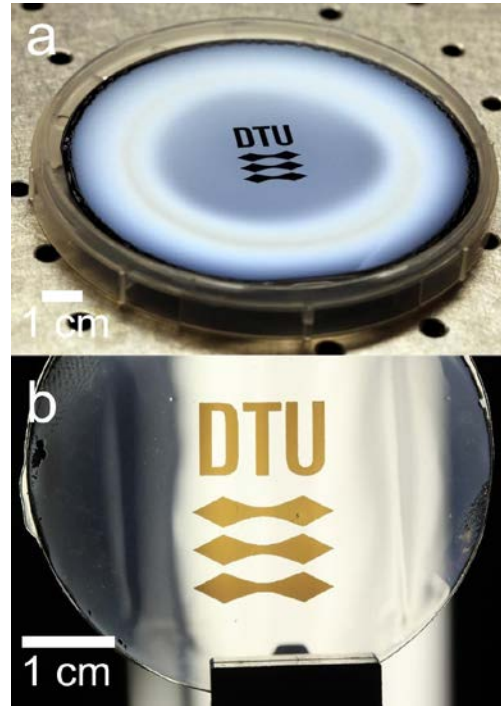


Figure 4: a) Silicon master with patterned black silicon structures. The bright ring is due to scattering from structures not completely removed. b) Replica in ORMOCOMP on glass substrate held against white light source, showing colored pattern.